Dec. 20, 1932. W. T. WINTRINGHAM 1,891,297

VARIABLE GAIN CIRCUIT DEVICE

Filed June 25, 1929 3 Sheets-Sheet 1

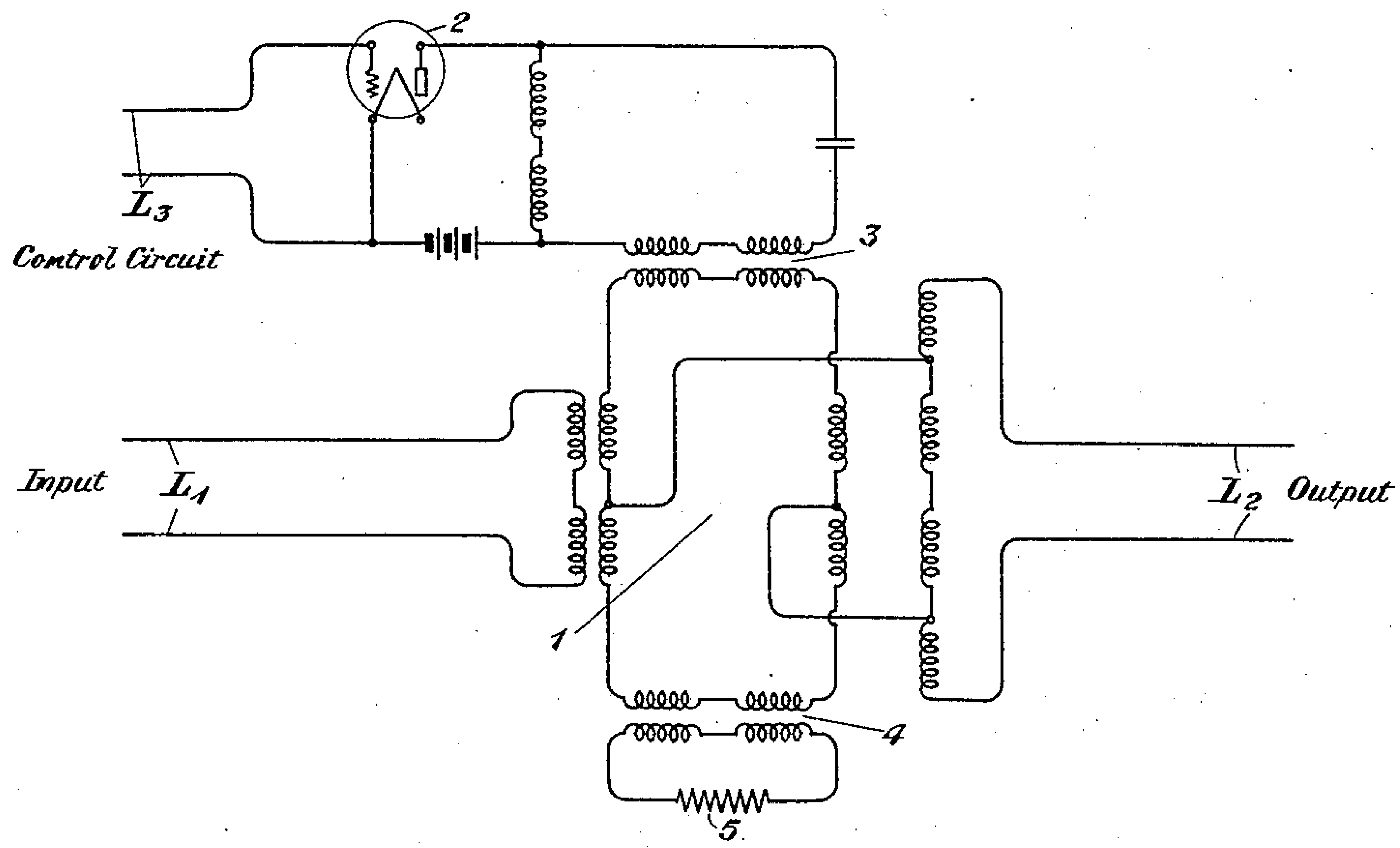

Fig. 1

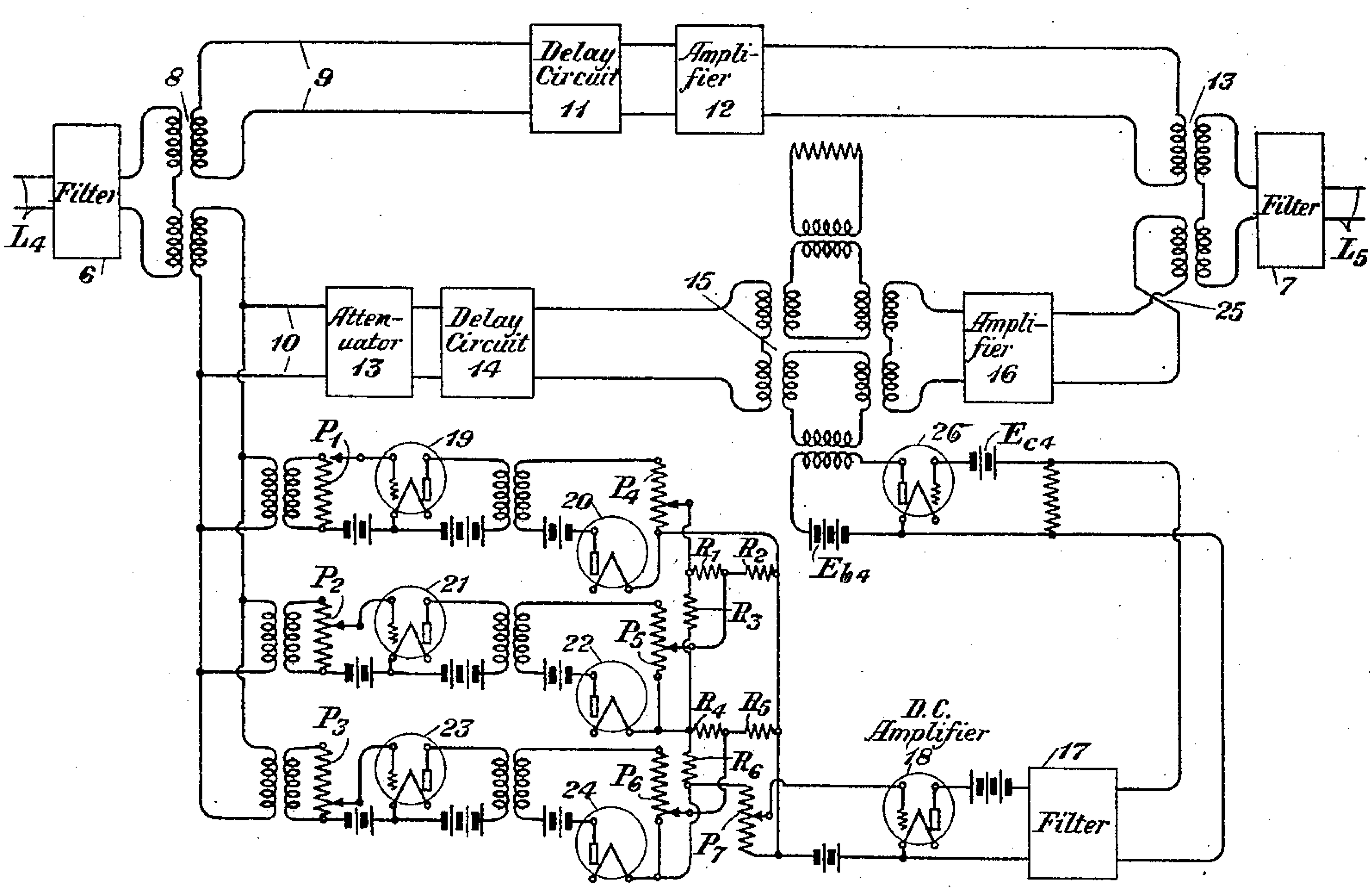

Fig. 2

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VARIABLE GAIN CIRCUIT DEVICE

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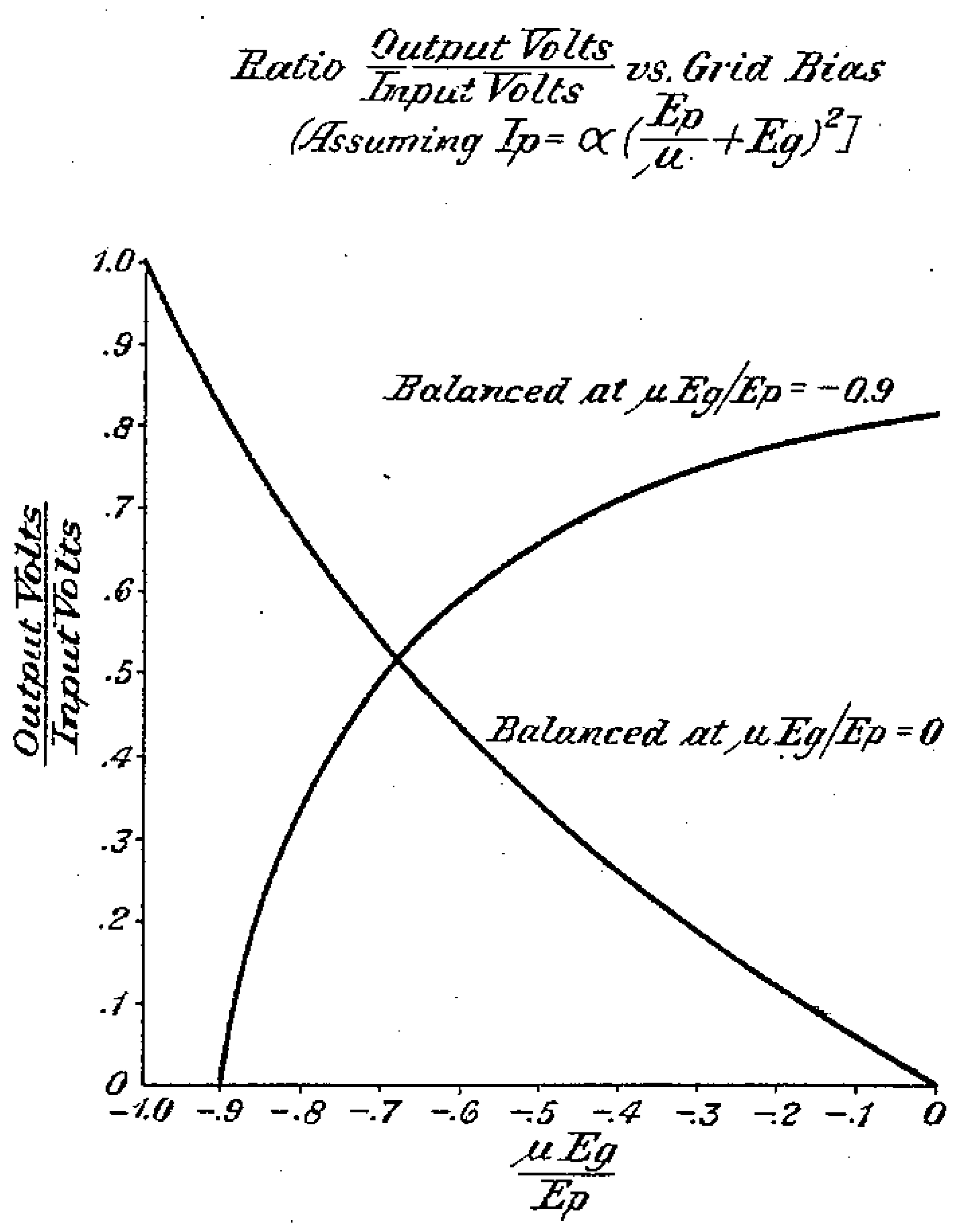

Fig. 3

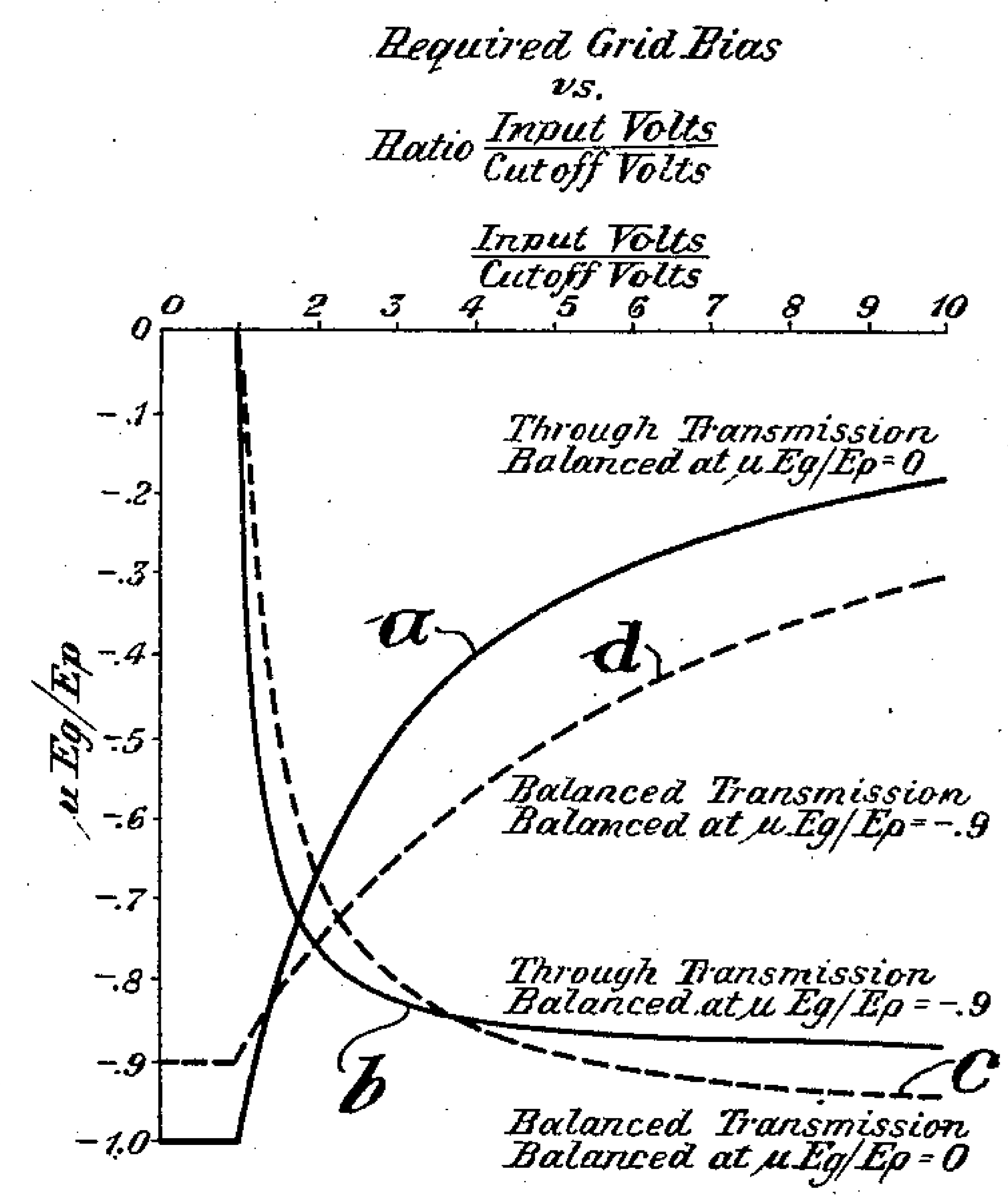

Fig. 4

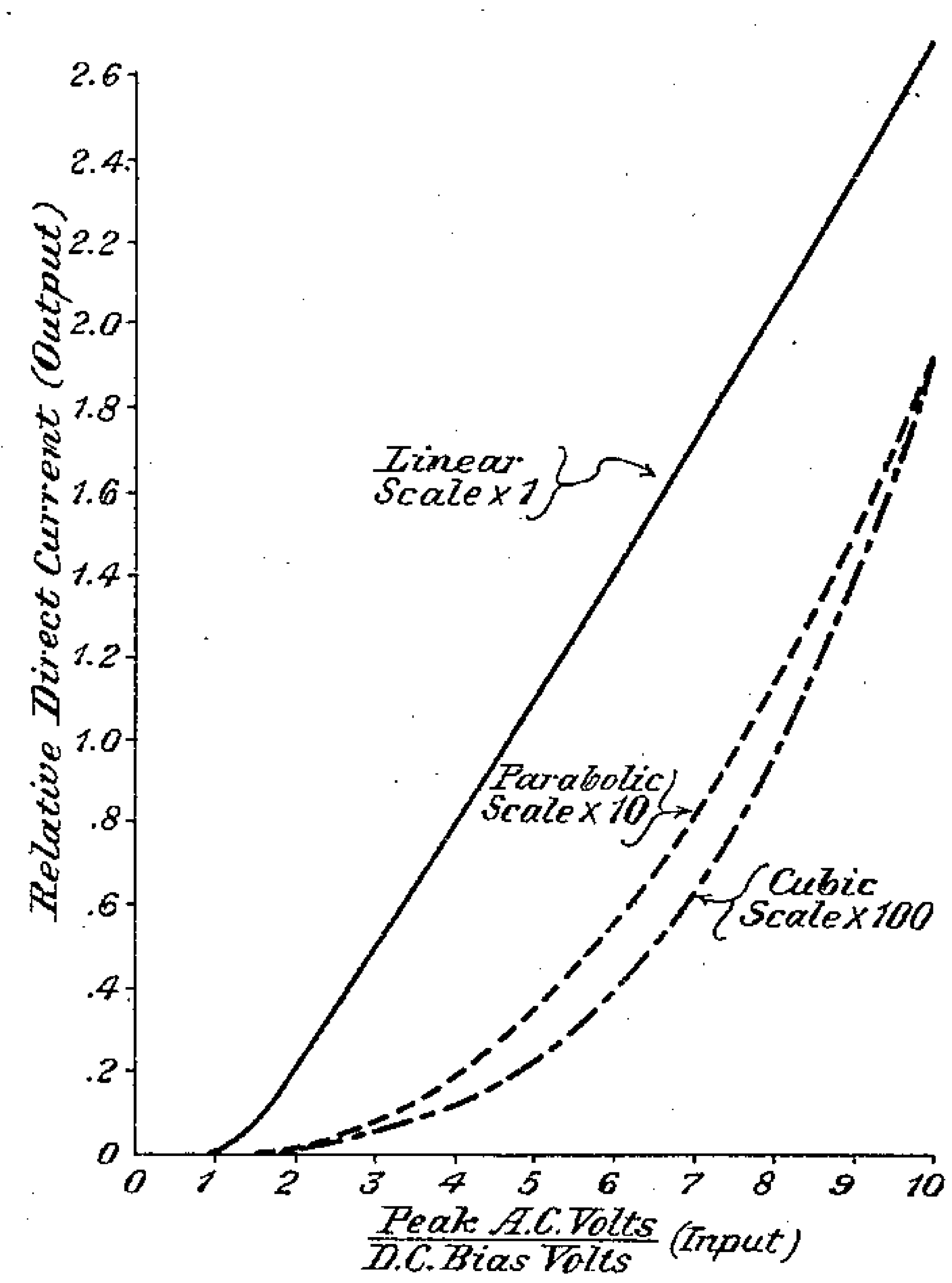

Fig. 5

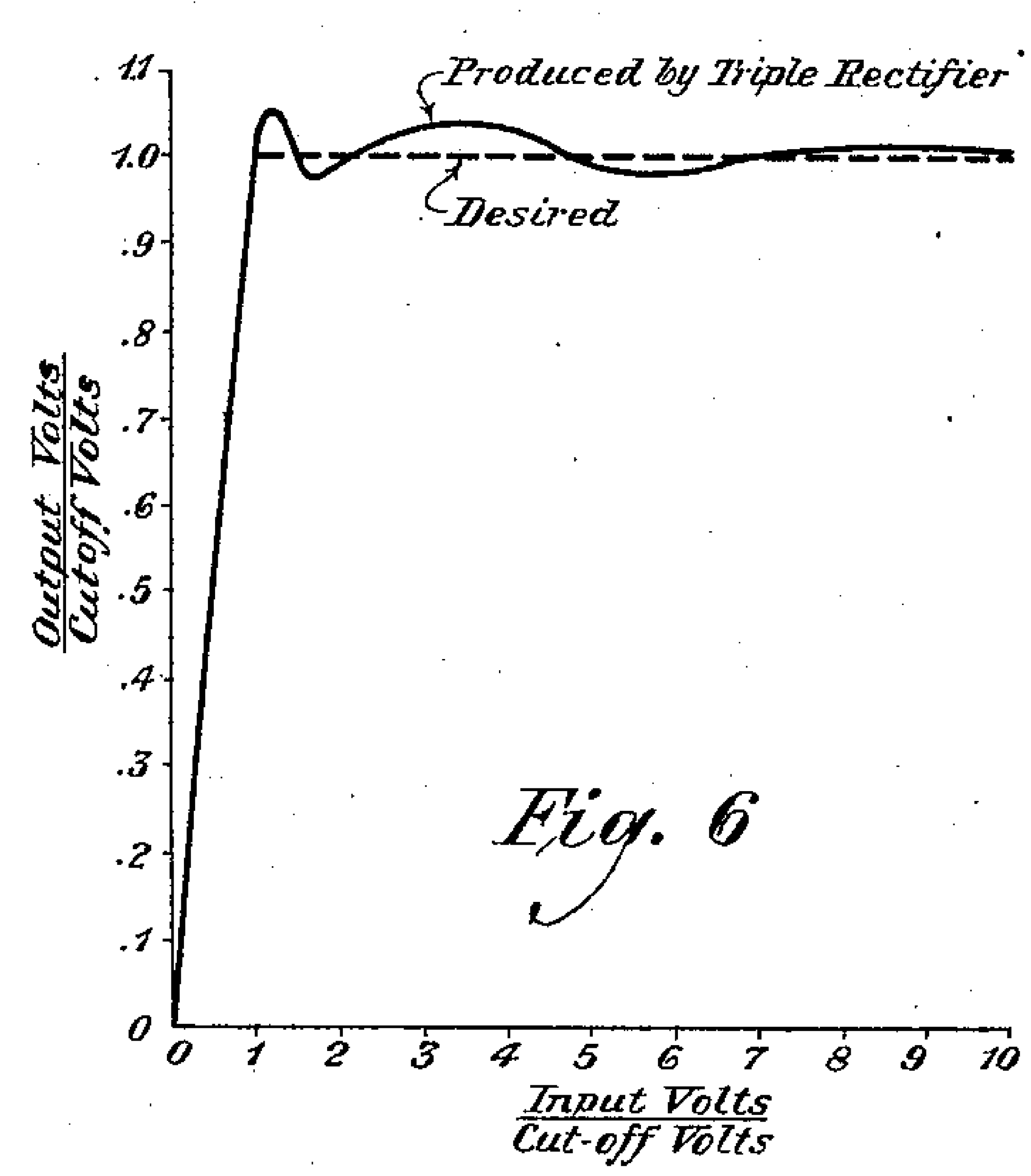

Fig. 6

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VARIABLE GAIN CIRCUIT DEVICE

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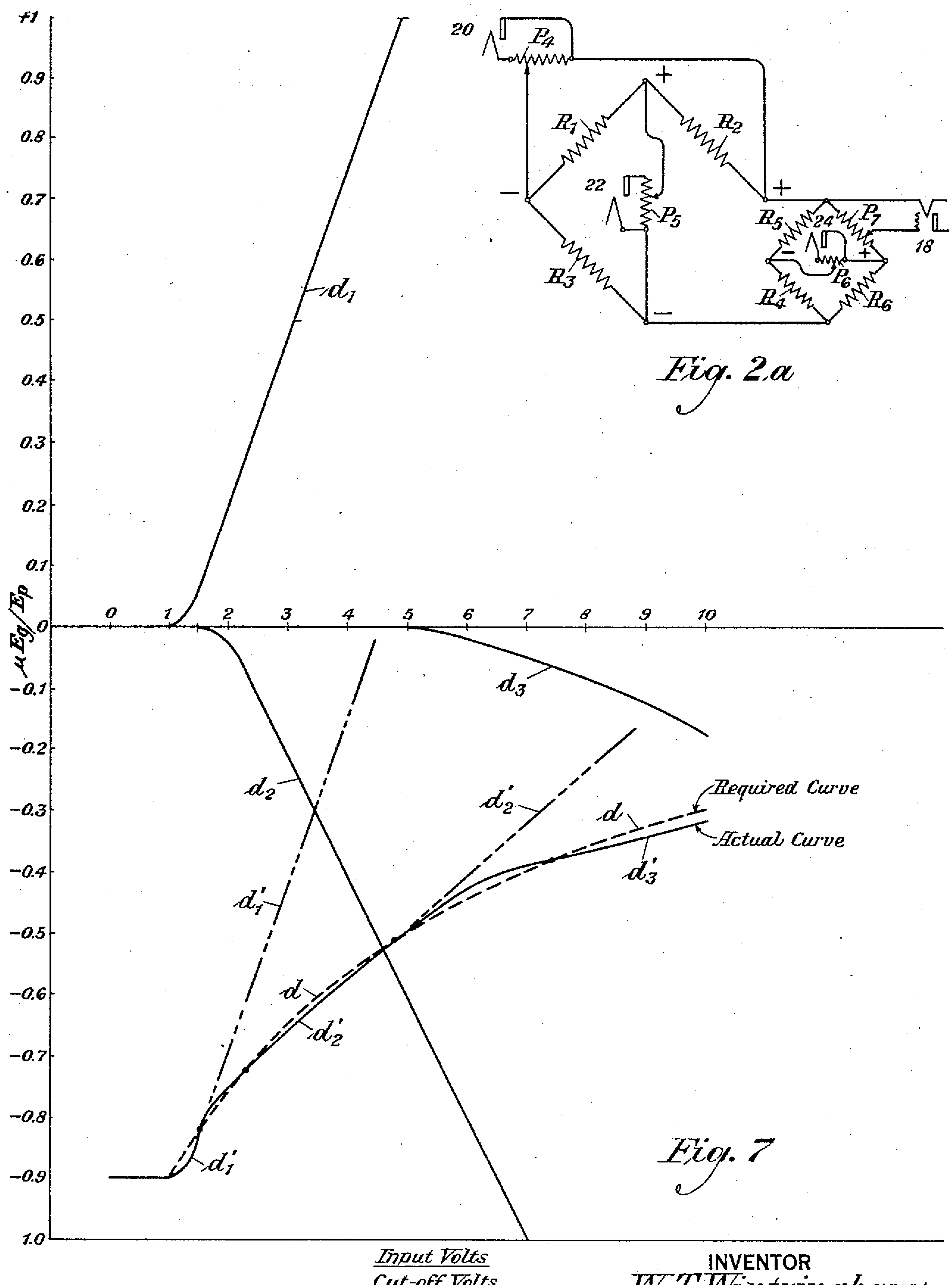

Fig. 2a

Fig. 7

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Patented Dec. 20, 1932 1,891,297

UNITED STATES PATENT OFFICE

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VARIABLE GAIN CIRCUIT DEVICE

Application filed June 25, 1929. Serial No. 373,679.

This invention relates to transmission systems and more particularly to an improved means for introducing gain or loss in the circuits of such systems.

In the variable gain circuit arrangements of this invention there is included in the transmission circuit a hybrid coil. A control circuit is provided which includes a vacuum tube device. The plate circuit of this vacuum tube is connected to the "line" terminals of the hybrid coil and a balancing network is provided across the "network" terminals of the hybrid coil. By varying the grid potential on the vacuum tube in the control circuit, the plate circuit impedance of this tube is changed and hence causes a change in the "hybrid balance" in the hybrid coil circuit. This in turn will result in variations in the loss introduced by the hybrid coil in the transmission circuit and such variations in loss may be controlled by the potentials applied to the control circuit.

A specific illustration of a situation wherein the variable gain device of this invention might be utilized to advantage would be in systems wherein it might be desired to limit the power or voltages to be transmitted over a circuit therein. One of the methods of limiting the power or voltages which may be transmitted over a circuit comprises dividing the main transmission path into two branch circuits and connecting the output circuits of these branch circuits in opposition to another section of the main transmission circuit. Through one of these branch paths, provided with an amplifier and a delay circuit, the signals pass in the ordinary way. In the other branch path there may be included the variable gain device of this invention. The control circuit of the device will be effected by the incoming signal energy and the control tube and hybrid coil combination will be so adjusted that for values of signals below the desired cut-off point, little or no power will be transmitted through the device, thereby leaving the first mentioned branch path to be normally the dominant one. The control tube and hybrid coil arrangement in the second branch path will also be so adjusted that when the signaling power approaches the point at which cut-off is desired, the transmission effectiveness of the second branch path increases. As the output circuits of the two branch paths are connected in opposition to another section of the main line, this transmission at the higher levels through the second branch path is made to oppose the normal transmission through the first branch path, thereby effecting a limiting value of the overall transmission through the circuit. Other features and applications of the arrangements of the invention will appear more fully from the detailed description thereof hereinafter given.

The invention may be more fully understood from the following description together with the accompanying drawings in the Figures 1, 2, 2(*a*), 3, 4, 5, 6 and 7 of which the invention is illustrated. In Fig. 1 is a circuit diagram embodying the invention. Fig. 2 is a circuit diagram showing the arrangements of the invention as applied to an arrangement for voltage limiting purposes. Fig. 2(*a*) is a schematic diagram showing the double bridge arrangement of Fig. 2. Figs. 3, 4, 5, 6 and 7 are graphical illustrations of certain of the operating principles of the invention.

In Fig. 1 is shown a portion of a transmission circuit comprising an input section L_1 and an output section L_2. These two line sections are interconnected by the hybrid coil 1. Connected by means of transformer 3 to the "line" side of the hybrid coil is the output or plate circuit of a three-element vacuum tube 2. This tube is connected to a control circuit L_3. Connected by means of transformer 4 to the "network" side of the hybrid coil is a resistance element 5. The voltage E_g applied to the control circuit L_3 will change the bias on the grid of tube 2 and hence vary the current in the plate circuit of tube 2 and thus vary the impedance of the plate circuit of the tube. This, in turn, will vary the hybrid balance of the hybrid coil arrangement 1 and thus change the loss between the drop terminals thereof, or, in other words, between L_1 and L_2. Accordingly, it will be possible to vary the gain in the circuit comprising line sections L_1 and L_2

by means of the potentials applied to the control circuit L_3.

It may be shown that the "hybrid balance", or the ratio of the current in the output circuit of a hybrid coil so connected, to the current when either the line or the net is open or short-circuited is:

$$B=\left|\frac{L-N}{L+N}\right|$$

where N=network impedance
L=line impedance

It is likewise well known that the plate impedance of a vacuum tube whose plate current may be expressed as:

$$i_p=a\left(\frac{E_p}{\mu}+E_g+\epsilon\right)^2$$

is:

$$r_p=\frac{\mu}{2a\left(\frac{E_p}{\mu}+E_g+\epsilon\right)}$$

If the hybrid coil is balanced at $E_g=E_{go}$; the hybrid balance is:

$$B=\left|\frac{\frac{\mu E_{go}}{E_p}-\frac{\mu E_g}{E_p}}{2+\frac{\mu E_{go}}{E_p}+\frac{\mu E_g}{E_p}}\right| \qquad (1)$$

where it is assumed that the contact potential ϵ is negligible. Equation (1) is plotted in Fig. 3 of the drawing, for

$$\frac{\mu E_{go}}{E_p}=0 \quad \text{and} \quad \frac{\mu E_{go}}{E_p}=-0.9.$$

Solving equation (1) for $\frac{\mu E_g}{E_p}$:

$$\frac{\mu E_g}{E_p}=\frac{\mu E_{go}}{E_p}\left(\frac{1-B}{1+B}\right)-\frac{2B}{1+B} \qquad (2)$$

and the change in bias required to give a certain balance (B) is given by:

$$\Delta\frac{\mu E_g}{E_p}=\frac{\mu E_g}{E_p}-\frac{\mu E_{go}}{E_p}$$

or

$$\Delta\frac{\mu E_g}{E_p}=\pm\frac{2B}{1\pm B}\left(\frac{\mu E_{go}}{E_p}+1\right) \qquad (3)$$

By means of equation (3) it is possible to calculate the change in bias required for every value of voltage input to this circuit element to produce any desired load characteristic.

The arrangements of the invention, as shown in Fig. 1, might be utilized as a voltage limiting device in instances where it is desired that the output voltage increase linearly with the input voltage up to a critical value and remain constant for further increases of the input voltage beyond that point. Under such conditions, the device might be so placed that transmission would normally take place directly therethrough. In other words, line sections L_1 and L_2 would be directly connected in the main transmission circuit and the control circuit L_3 might be bridged through suitable amplifiers and rectifiers across line L_1 in order to be effected by the incoming voltages. The hybrid coil 1 would normally be unbalanced to permit transmission therethrough. The grid bias on tube 2 would be so adjusted that when the input voltage increased to a critical value the balance of the hybrid coil would be effected to approach a better balance and hence effect a limiting value on the transmission therethrough.

In Fig. 2, the arrangements of the invention are shown as embodied in a specific type of voltage limiting circuit arrangement. In this arrangement the transmission line comprises the input section L_4 which includes a band pass filter 6, the lower cut-off of which is greater than a frequency corresponding to the rate at which it is desired to limit the output. The input signal is divided at the transformer 8 into two branch circuits 9 and 10. Circuit 9 includes a delay circuit 11 and an amplifier 12 and is connected by transformer 13 to the filter 7 and the output section L_5 of the transmission line. The branch circuit 10 includes an attenuator 13, a delay circuit 14, the hybrid coil-control tube combination of this invention, and an amplifier 16 and is connected through a reversal 25 to the transformer 13 and the output line section L_5. Due to the reversal 25 the currents from the two branch circuits are applied to the output circuit L_5 in opposition. Normally the hybrid coil 15 is balanced so no transmission takes place over the branch 10. When the hybrid coil 15 is totally unbalanced, the amplifier and attenuator in these two paths may be so adjusted that the voltage at the output from the second path is 1.2 times that from the first path. The total delay in these two paths should be identical so that the turnover 25 in the second path puts the two sets of voltages at the output transformer 13 in phase opposition for all frequencies.

In order to supply the controlling voltage for determining the unbalance of hybrid coil 15 three amplifiers 19, 21 and 23 are connected across the input of the branch path 10, the outputs of which amplifiers operate three linear rectifiers 20, 22 and 24. The output of these rectifiers is connected to the D. C. amplifier 18, filter 17, and thence to the grid of the control tube 26 whereby the hybrid balance of the hybrid coil 15 may be controlled. Three rectifiers are provided because it is necessary to combine potentials from rectifiers of different characteristics in order to supply the required grid bias for the tube 26, as will now be explained.

The required grid biases, as determined by equation (2), above mentioned, as functions of the input voltage for conditions such as shown in Figs. 1 and 2, and for each of two initial grid biases, are given graphically in Fig. 4. It will, of course, be apparent that the elements may be designed to produce a balance of the hybrid coil at any particular voltage applied to the grid of the control tube 26. Assuming balance at a given grid voltage, the curve of the variation in applied grid potential corresponding to a given load characteristic will also depend on whether transmission is normally to take place through the path 10, or not—in other words, it will depend on whether hybrid coil 15 is normally balanced or normally unbalanced. In Fig. 4 the full line curves are plotted for the case where hybrid coil 15 is normally unbalanced, curves a and b respectively representing the potential variations when balance occurs at

$$\frac{\mu E_g}{E_p}=0 \text{ and } \frac{\mu E_g}{E_p}=-.9.$$

The dotted line curves c and d are corresponding curves for the case where hybrid coil 15 is normally balanced. It is assumed for the purpose of determining these curves that the gain, in tandem with the gain circuit element of the invention, is such as to produce a voltage ratio through it for the completely unbalanced condition in the hybrid coil of 1.0 for through transmission and 1.2 for the balanced condition.

To produce such bias changes as are necessary to produce the load characteristics that have been indicated as desirable for voltage limiters requires rather special rectifier characteristics. We may specify a rectifier characteristic such that the current flowing in the rectifier is zero for all negative applied potentials, and may be expressed as:

$$i_p=a_1e+a_2e^2+a_3e^3+\ \ldots$$

for all positive values of e. If then we place a negative D. C. bias on the rectifier of value E_c and impress a sinusoidal voltage of $E \cos \omega t$, the D. C. output of the rectifier becomes:

$$Ip=\frac{1}{\pi}\Big[a_1E\,(\sin\beta\pi-\beta\pi\cos\beta\pi)+\frac{a_2E^2}{1\cdot 2}\,(-3\cos\beta\pi\sin\beta\pi+(3-2\sin^2\beta\pi)\,\beta\pi)+$$
$$\frac{a_3E^3}{1\cdot 2\cdot 3}\,([15-11\sin^2\beta\pi]\sin\beta\pi-(5-2\sin^2\beta\pi)\,\beta\pi\cos\beta\pi)+\ldots\Big] \quad (4)$$

where

$$\beta\pi=\cos-1\frac{E_c}{E} \quad (5)$$

Equation (4) is plotted in Fig. 5, where all of the coefficients except a_1 are zero for the linear rectifier, all but a_2 zero for the parabolic rectifier, etc.

Let us assume that the hybrid coil 15 is to be normally balanced at

$$\frac{\mu E_{go}}{E_p}=-0.9$$

so that the required grid bias on the tube 26 will be as indicated by the curve d of Fig. 4. It becomes necessary to design a combination of rectifiers that will supply such a grid bias. A comparison of curve d with the curves of Fig. 5 indicates that the use of parabolic or cubic rectifiers is impractical and that better results may be obtained by a combination of linear rectifiers. By investigation involving trial and error methods, it was found that the required characteristic could be approximated by the use of three linear rectifiers, used as follows:

Rectifier No.	Bias	Relative output used
1	$-\ \ E_c$	+0.9
2	$-1.5\ E_c$	−1.0
3	$-5.0\ E_c$	−0.85

This combination of rectifiers used with the balanced transmission voltage limiter yields the load characteristic shown in Fig. 6. The manner in which this result was arrived at may be understood from a consideration of the curves of Fig. 7. Here, the dotted line curve represents the desired variation of grid bias for the tube 26. Full line curves d_1, d_2 and d_3 represent the characteristics of the rectifiers No. 1, No. 2 and No. 3. The characteristic of rectifier No. 1 is such that no rectified potential appears in its output until the applied voltage is equal to the desired cut-off. Rectifier No. 2 produces no rectified output until the applied voltage is 1.5 times the cut-off, and No. 3 produces no output until the applied voltage is 5 times the output. If the rectified potential of curve d_1 be superposed on the normal grid bias of the tube 26 produced by source E_{c4}, and said source produces a potential corresponding to

$$\frac{\mu E_g}{E_p}=-.9,$$

the curve d_1' results. It will be seen that the characteristic of the rectifier is too steep as the dashed part of curve d_1' rises rapidly above the desired curve d, the departure beginning at a ratio of input to cut-off corresponding to 1.5.

At this point rectifier No. 2 begins to supply potential to the tube 26, and its connection must be reversed with respect to rectifier No. 1 in order that it may supply an opposing potential. Its effective characteristic is, therefore, represented by curve d_2, which has a downward slope. By adding this curve to curve d_1', curve d_2' results. The latter crosses below the desired curve d, as shown in full line, but again rises above it, as shown by the dashed part of curve d_2'. The departure begins at a ratio of input to cut-off corresponding to 5. Here the third rectifier comes into play. Its output must be reversed in sign with respect to that of rectifier No. 1 as it must reduce the slope of the dashed part of curve d_2'. The addition of the potential represented by curve d_3 thus brings the resultant curve to the position plotted at d_3' in full line. The curves d_1, d_2 and d_3 are given the different slopes indicated by using the outputs of the rectifiers in the relative proportions 0.9 for No. 1, 1.0 for No. 2, and 0.85 for No. 3, as given in the preceding table. Obviously, the curve resulting from combining the outputs of these rectifiers in these proportions closely approximates the desired curve d of Fig. 7. The departure of the resultant curve from curve d in Fig. 7 causes the departure from the ideal flat characteristic above cut-off, as shown in Fig. 6.

Distortion can only be produced in the circuit of Fig. 2 (if the grid bias applied to the control tube be direct current varying at a sufficiently slow rate), by variation of the plate voltage of the control tube by the desired signal in the hybrid coil circuit. If this circuit element be placed at such a point that the voltages so placed on the control tube plate are negligible with respect to the effective plate voltage $(E_p+\mu E_g)$ this source of distortion is rendered as ineffective as may be desired.

As has been previously pointed out with respect to Fig. 2, there is connected across the input of branch path 10 three amplifiers, the outputs of which operate three linear rectifiers 20, 22 and 24. Rather than adjusting the biases on these rectifiers (Ec_1, Ec_2 and Ec_3) in the required ratios (1, 1.5 and 5), these biases can be made equal and the input signals reduced by means of the potentiometers P_1, P_2 and P_3 associated with the amplifiers in the ratios of 1, ⅔, and ⅕. This enables the use of identical rectifier circuits and in no way alters the operation of the device. The potentiometers P_4, P_5 and P_6 have such resistances that the voltage current characteristics of the rectifiers are linear.

Since the output from the three rectifiers must be connected to a common circuit, the resistance network comprising resistances R_1, R_2, R_3, R_4, R_5 and R_6 and potentiometer P_7 is provided. This network, when all of these resistances are equal, is a balanced double Wheatstone bridge such that voltages in any one rectifier can not appear in any other rectifier circuit as will be clear from the schematic diagram of Fig. 2(*a*). By suitable adjustments of potentiometers P_4, P_5 and P_6, the proper proportions of rectifier outputs appear across potentiometer P_7, (0.9, 1.0, and 0.85) and by proper reversal of connections in this resistance network, these increments of voltage have the proper signs.

The voltage across potentiometer P_7 is applied to the input of a D. C. amplifier 18, the output of which is connected to a low pass filter 17. The cut-off frequency of this filter is determined by the maximum rate at which it is desired that limiting take place. The output from the filter is applied to a resistance in the grid circuit of the control tube 16 to vary the grid bias thereof and hence vary the degree of balance in the hybrid coil 15. The grid and plate batteries (Ec_4 and Eb_4) for the control tube have such values that

$$\frac{\mu E_{go}}{E_p}=-0.9.$$

While the invention has been disclosed as embodied in certain specific arrangements which are deemed desirable, it is understood that it is capable of embodiment in many and other widely varied forms without departing from the spirit of the invention as defined by the appended claims.

What is claimed is:

1. A transmission system including a double Wheatstone bridge comprising four arms forming one bridge, one arm of said bridge comprising four arms forming a second bridge, a source connected to one pair of opposite neutral points of said first bridge, a second source connected to the remaining neutral points of said first bridge, a third source connected to opposite neutral points of said second bridge, and a work circuit so related to said double Wheatstone bridge as to receive transmission from each of said sources.

2. A transmission system comprising a work circuit, a plurality of sources of rectified current for said work circuit, and a network for relating said sources to said work circuit, said network having a plurality of separate sets of terminals each set of which is conjugate with respect to the other sets of terminals, said plurality of sources being connected to said separate sets of terminals, whereby transmission may simultaneously take place from said sources to said work circuit without one source reacting on the others.

3. A transmission system comprising a work circuit, more than two sources of rectified current for said work circuit, and a network for relating said sources to said work circuit, said network having a plurality of separate sets of terminals each set of which is conjugate with respect to the other sets of terminals, said plurality of sources being connected to said separate sets of terminals,

whereby transmission may simultaneously take place from all of said sources to said work circuit without interaction between said sources.

4. A transmission system comprising a voltage operated translating device, a plurality of rectifiers for supplying rectified waves to said voltage operated device, and a network for relating said rectifiers to said translating device, said network having a plurality of separate sets of terminals each set of which is conjugate with respect to the other sets of terminals, said plurality of rectifiers being connected to said separate sets of terminals, whereby rectified waves may be simultaneously supplied from said rectifiers to said translating device without interaction between said rectifiers.

5. A transmission system comprising a work circuit, more than two supply sources for said work circuit, a double Wheatstone bridge network having a plurality of separate sets of terminals each of which is conjugate with respect to the other sets of terminals, means to connect said supply sources to different sets of said terminals, whereby each source will be conjugate with respect to the other sources, and means to relate said work circuit to the bridge so as to receive transmission from all said sources.

6. A transmission system comprising a voltage operated translating device, more than two rectifiers for supplying rectified waves to said translating device, a double Wheatstone bridge network having a plurality of sets of terminals each set of which is conjugate with respect to the other sets of terminals, means to connect the outputs of said rectifiers to different sets of said terminals, whereby the rectifiers will be so related that each will be conjugate with respect to the others, and means to relate said translating device to said bridge so as to receive rectified waves from all said rectifiers.

7. A transmission circuit comprising two line sections, a hybrid coil interconnecting said line sections, a balancing element connected to the net work side of said hybrid coil, an impedance controlling device connected to the line side of said hybrid coil, a control circuit for said impedance controlling device, a plurality of rectifiers for rectifying waves applied to one of said line sections, control means associated with said rectifiers to control the relationship between the input and output waves thereof, said control means being adjusted to produce predetermined different relationships between the input and output waves of the different rectifiers, connections to combine the outputs of said rectifiers in said control circuit in any predetermined polarity relationship with respect to each other, and determining means associated with said connections to determine the relative proportions of the outputs of said rectifiers, whereby the relationships between the input and output waves of the several rectifiers and the relative proportions of the outputs of said rectifiers may be so predetermined, and the outputs combined in such relative polarity as to control the balance of said hybrid coil in a predetermined manner.

8. A transmission circuit comprising two line sections, a hybrid coil interconnecting said line sections, a balancing element connected to the network side of said hybrid coil, an impedance controlling device connected to the line side of said hybrid coil, a control circuit for said impedance controlling device, a plurality of rectifiers for rectifying waves applied to one of said line sections, control means associated with said rectifiers to control the relationship between the input and output waves thereof, said control means being adjusted to produce predetermined different relationships between the input and output waves of the different rectifiers, connections to combine the outputs of said rectifiers in said control circuit in any predetermined polarity relationship with respect to each other, and determining means associated with said connections to determine the relative proportions of the outputs of said rectifiers in said control circuit, whereby the relationships between the input and output waves of the several rectifiers and the relative proportions of the outputs may be so predetermined and the outputs combined in such polarity in said control circuit as to produce a potential therein bearing a relation to a wave applied to said line section such that the potential varies directly with the applied wave for all values of applied wave on one side of a cut-off value while remaining substantially constant with changes of applied wave on the other side of the cut-off value.

9. A line section divided into two branches, said branches having their output circuits connected in opposition to each other to another section of said line, means including a vacuum tube for varying the transmission equivalent of one of said branches, a plurality of rectifiers associated with said line, control means associated with said rectifiers to control the relationship between the input and output waves thereof, said controlling means being adjusted to produce predetermined different relationships between the input and output waves of the different rectifiers, means to combine the outputs of said rectifiers in any predetermined polarity relationship with respect to each other, determining means associated with said connections to determine the relative proportions of the outputs of said rectifiers, whereby the relationships between the input and output waves of the several rectifiers and the relative proportions of the outputs of said recti-

fiers may be so predetermined and the outputs combined in such polarity as to apply a potential to said vacuum tube bearing a relation to a wave applied to said line such that the potential varies directly with the applied wave for all values of applied wave on one side of a cut-off value while remaining substantially constant with changes of applied wave on the other side of said cut-off value.

10. A transmission circuit comprising two line sections, a hybrid coil interconnecting said line sections, a balancing resistance connected to the network side of said hybrid coil, the plate circuit of a vacuum tube connected to the line side of said hybrid coil, a control circuit for varying the impedance of said vacuum tube plate circuit, a plurality of translating devices having different characteristics and each translating waves from one of said line sections and applying the translated product to said control circuit, the translating devices being so chosen with respect to their input-output characteristics that their outputs may be combined in said control circuit to produce a controlling potential in said control circuit which varies with the wave applied to said line section in a predetermined manner for all values of applied wave on one side of a cut-off value and which remain substantially constant with changes of the applied wave on the other side of said cut-off value.

11. A transmission circuit comprising two line sections, a hybrid coil interconnecting said line sections, a control circuit for controlling the degree of unbalance in said hybrid coil, a plurality of translating devices having different characteristics and each translating waves from one of said line sections and applying the translated product to said control circuit, the translating devices being so chosen with respect to their input-output characteristics that the outputs may be combined in said control circuit to control the degree of balance existing in said hybrid coil so that the coil will be substantially balanced for all values of applied voltage on one side of a cut-off value and will be unbalanced for all values on the other side of said cut-off value.

12. A transmission circuit comprising two line sections connected in conjugate relationship with each other, a control circuit, means in said control circuit responsive to voltages impressed thereon for varying the degree of conjugacy in the relationship between said line sections, a plurality of translating devices having different characteristics and each translating waves from one of said line sections and applying the translated product to said control circuit, the translating devices being so chosen with respect to their input-output characteristics that the outputs may be combined in said control circuit to produce a voltage therein such that the voltage responsive means in the control circuit will vary the degree of conjugacy in the relationship between the line sections to render the sections substantially conjugate for all values of impressed voltage on one side of a cut-off value while rendering them nonconjugate for all values on the other side of the cut-off value.

13. A line divided into two branches, said branches having their output circuits connected to another section of the line in opposition to each other, means in one of said branches controlled by the voltage applied thereto for regulating the gain in said branch, said means comprising a hybrid coil interconnecting two sections of said branch circuit, a balancing resistance connected to the network side of said hybrid coil, the plate circuit of a vacuum tube connected to the line side of said hybrid coil, a control circuit connected to one of the two sections of said branch circuit for varying the impedance of said vacuum tube circuit, a plurality of translating devices having different characteristics and each translating waves from one of said line sections and applying the translated product to said control circuit, the translating devices being so chosen with respect to their input-output characteristics that their outputs may be combined in said control circuit to produce a controlling potential therein which varies with the applied wave in a predetermined manner for all values of applied wave on one side of a cut-off value and which remains substantially constant with changes of the applied wave on the other side of said cut-off value.

14. A line divided into two branches, said branches having their output circuits connected to another section of said line in opposition to each other, a hybrid coil interconnecting two of the sections of one of said branch circuits, a control circuit for controlling the balance of said hybrid coil, a plurality of translating devices having different characteristics and each translating waves from one of said line sections, the translating devices being so chosen with respect to their input-output characteristics that the outputs may be combined in said control circuit to so control the balance of said hybrid coil that the coil will be substantially balanced for all values of applied voltage on one side of a cut-off value and will be unbalanced for all values on the other side of said cut-off value.

15. A line divided into two branches, said branches having their output circuits connected to another section of said line in opposition to each other, a hybrid coil interconnecting two of the sections of said branch circuit, a control circuit connected to one of the sections of said last mentioned branch circuit, a vacuum tube device in said control circuit having its plate circuit connected to

the line side of said hybrid coil, a plurality of translating devices in said control circuit, said translating devices having different characteristics and each translating waves from one of said line sections and applying the translated waves to said vacuum tube device, said translating devices being so chosen with respect to their input-output characteristics that their outputs may be combined to supply the said vacuum tube device controlling potentials which vary with waves applied to said line in a predetermined manner for all values of applied wave on one side of a cut-off value and which remains substantially constant with changes of applied wave on the other side of said cut-off value.

In testimony whereof, I have signed my name to this specification this 24th day of June, 1929.

WILLIAM T. WINTRINGHAM.